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AUTHOR Mamlok, Rachel; Dershimer, Charles; Fortus, David; Krajcik, Joe; Marx, Ron

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ABSTRACT

The purpose of this study was to document the iterative development of a design-based science curriculum called Learning Science by Designing Artifacts (LSDA). The study refers to the enactment of the Safer Cell Phones curriculum in a high school located in the Midwest. The curriculum was a 5- or 9-week unit in an 18-week science elective course. In the initial version of the LSDA curriculum, students were actively engaged in the creation and presentation of their ideas while learning about the field of design and science content. However, the researchers had concerns regarding how well the curriculum was supporting the students in learning science. During this development process, the development team underwent a significant shift in their understanding of the theoretical framework called design-based science (DBS). Over time the researchers changed their ideas toward having students act as product designers using a design cycle instructional framework that incorporated science content. This paper documents how the changes in the curriculum design and the researchers' evolving understanding of DBS are informed and supported by data on student learning and student motivation in the classroom. The results of this work have implications for future reform-based DBS curricula. (Contains 15 references.) (PVD)

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# Learning Science by Designing Artifacts (LSDA) - A Case Study of the Development of a Design-Based Science Curriculum

by

Rachel Mamlok
Charles Dershimer
David Fortus
Joe Krajcik
Ron Marx



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# Learning Science by Designing Artifacts (LSDA) - A Case Study of the Development of a Design-Based Science Curriculum.

Rachel Mamlok
- Weizmann Institute of Science, Rehovot, Israel

Charles Dershimer, David Fortus, Joe Krajcik, Ron Marx
- University of Michigan, Ann Arbor Michigan

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## INTRODUCTION

Reform in science education is a complex process. Successful innovations require the integration of a variety of different educational activities while addressing the system undergoing reform. James Gallagher (2000) comments that current "policy makers and scholars are recommending multidimensional actions that address an array of entities" to produce results in reform (pg. 399). He notes that issues such as teaching all students, inclusion of socio-scientific content, involvement of computers, and curricula that place greater instructional emphasis on scientific processes and on the history of development of scientific theories are important components of science education reform (Gallagher, 2000).

However, research on current instructional reform efforts highlights the multifaceted difficulties that accompany science education reform. Successful reform cannot be based on an innovative curriculum alone. The reform effort must address several issues related to the organizational culture of schools, the capability of the educators involved in terms of their understandings and expertise, and the policy and management structure concerns of the school system being affected (Blumenfeld et al., 2000). Successful reform requires innovators to study and implement multiple issues simultaneously in order to understand how to create a capacity to sustain the reform and increase the chances of success (Blumenfeld et al., 2000).

Over the course of the 1999-2000 school year, the Center for Highly Interactive Computing in Education (hi-ce) at the University of Michigan worked to develop reform-focused science curricula. hi-ce has a history of involvement in science education reform in both urban and suburban settings. The development of the science curricula was one component of a larger project called the Primary Sources Network (PSN), a federally funded Technology Innovation Challenge Grant. The PSN project is working to create both science and social studies curricula that meet several goals. One goal of the project is to create a framework for understanding how primary sources can be used to support learning in high school classrooms and to adapt, design and develop learning technologies to support the use of primary sources. These innovative science

curricula address several of the reform issues noted above by Gallagher. They new curricula involve topics that are of popular interest to most students, they have students learning through the use of computers, and they have students learning standards-based science content while studying and designing artifacts.

The purpose of this study is to document the iterative development of this Design-Based Science curriculum (LSDA – Learning Science by Designing Artifacts). During the development process, the development team underwent a significant shift in their understanding of the theoretical framework called Design-Based Science (DBS). Initially, we created curricula that had students learning about design as a set of Science-Technology-Society (STS) content topics. Over time we changed our ideas toward having students act as product designers using a design cycle instructional framework that incorporated science content. This paper will document how the changes in the curriculum design and our evolving understanding of the theoretical framework called DBS are informed and supported by our data on student learning and student motivation in the classroom. The results of this work have implications for future reform based DBS curricula.

**OBJECTIVES**

In the initial version of the LSDA curricula, enacted during the first semester of the school year, students were actively engaged in the creation and presentation of their ideas while learning about the field of design and science content. However, we had concerns regarding how well the curriculum was supporting the students in learning science. Our initial data from interviews revealed that students enjoyed the curricula, and the attitude questionnaires indicated that they had positive attitudes about science while using the curricula. However, we felt that too much time was being spent on explicitly teaching about the design process, leaving less time to deal with science than we would have liked. We then engaged in a process of redesigning the curriculum and gathering data to address our research objective:

> *Can we redesign the curriculum to improve the depth of science content without causing a decline in students' attitudes towards the curriculum and towards science?*

Our research involved comparing the different versions of our curriculum focusing on students' attitudes and students' content knowledge. We proposed to make changes to the second semester's enactment of the curriculum that would remove the lessons about the discipline of design, and increase the depth of the science lessons. Classroom activities would still include the process elements of design: working with design specifications, creating and revising models and drawings, and receiving feedback on work through pinups and critiques. These curriculum modifications came about as our understanding of the innovative instructional process Design Based Science evolved and as we created materials that better matched what was required for it to be successfully enacted.

## THEORETICAL FRAMEWORK

The reform-focused science curricula developed by the hi-ce group at the University of Michigan are founded on a social constructivist perspective (Blumenfeld et al., 1997; Singer et al., 2000). These curricula can be characterized by four prominent learning features:

a) *active construction*, which states that students must be actively engaged in explaining, generalizing, hypothesizing, representing, etc., in order for deep understanding to develop;
b) *situated cognition*, which states that learning occurs best when contextualized in situations meaningful to the students;
c) learning occurs through repeated exposure to the practices of a *community* of practitioners, and
d) that communities of practitioners are essentially communities of disciplinary *discourse*.

In addition to incorporating these learning features, the Learning Science by Designing Artifacts (LSDA) curricula have three main characteristics: they incorporate the use of primary sources, they use the Design-Based Science (DBS) framework, and they make extensive use of existing, adapted and new computer technologies.

Design-Based Science (DBS) is a particular form of Project-Based Science (PBS) in which students' activities focus on the need to design artifacts that are related to real-world problems chosen to be interesting and challenging to the students. For example, the design goal of the curriculum with which this research deals is, *Can I design a cell-phone that minimizes radiation, battery, and sound hazards without compromising customer appeal?* In DBS, the design of the artifacts is not a culminating activity at the end of the curriculum, but rather it is the framework around which all the learning activities are organized.

The cell-phone curriculum begins by giving the students design specifications that specify the requirements that their cell-phones will have to meet. Having the kids watch a video of an ABC 20/20 story on cell-phone safety sets the context of cell-phones as potential sources of health and environmental hazards. The kids then read a newspaper article on the same subject and a classroom discussion is held about the facts and the opinions expressed in the video and in the newspaper article. The students then engage in a series of units that are organized around the different stages of the design process. Students do Internet research on the different components of a safer cell-phone (environmentally friendly batteries, safe sound levels, and reports on electromagnetic radiation levels). Students examine a museum collection of phones to summarize the changes in the form and function that telephones have gone through since their invention. Students collect data from teenagers about their daily use of phones and summarized this in a report. There are laboratories on building a battery and studying battery chemistry, building a speaker and studying sound waves, and learning about electromagnetic radiation from a series of demonstrations using TV antennas and a broadcast signal. Throughout this process, the students are participating in the design studio process by

utilizing cycles of production and reflection. Students express their ideas through drawings and written essays and then get feedback on their ideas in pin-up and critique sessions.

Other than the *Science by Design* series developed at TERC (TERC, 2000) and the *Learning Science by Designing Artifacts* (LSDA) curricula created by the hi-ce group at the University of Michigan, we are unaware of other high school Design-Based Science curricula that have been developed in the United States. A middle school DBS curricula called *Learning By Design* (LBD) has been developed at Georgia Tech (Kolodner, et al., 1998) and a program that engages 4th and 5th grade students in creating science-oriented computer simulations has been developed at UCLA (Kafai and Ching, 1998). A number of other researchers write of using design in primary school classrooms (Roth, W-M., 1996; Penner, D.E., et al., 1997), but these authors are more interested in the development of models by the students and the importance of these artifacts in the learning process; they are not explicitly attempting to use design as a vehicle for teaching science.

As mentioned earlier, after the first enactment of the cellphone curriculum, we felt that too much time had been spent learning explicitly about the design process in comparison with the time spent learning about science. We decided to modify the curriculum, to try and make the design process a part of the pedagogical framework without having to deal with it explicitly, freeing time to go deeper into the science content, but still allowing the students to engage in a design process.

The curriculum went through two major revisions in content, activities, and organization. Each revision was based on a better understanding on our part of how to incorporate science content into a design framework. The table in appendix A summarizes the main differences between the three versions. In the first version of the curriculum, students spent as much time learning explicitly about design as they spent learning about science. In the second version more time was given to science, while in the third version almost all the lessons about design were dropped. Instead, a cycle we call the DBS Learning Cycle (figure 1 below), which is structured around the design process, became the framework for how classroom activities progressed. This allowed the students to engage in a design process without having to be explicitly taught about this process.

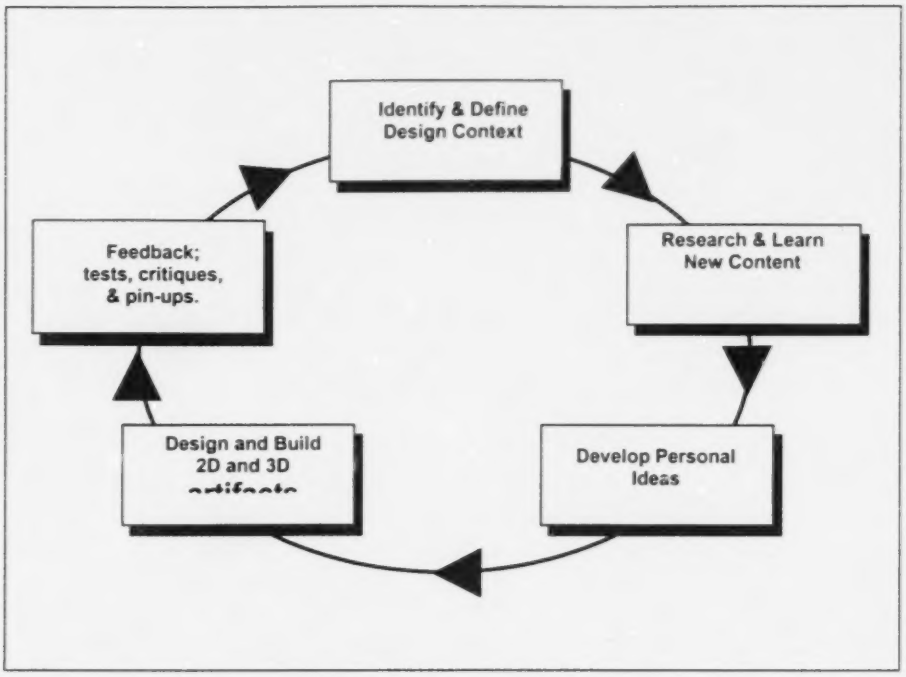


**Figure 1: The design based science (DBS) learning cycle**

As the DBS Learning cycle shows, the students are actively engaged in *constructing* knowledge by asking and refining questions, developing personal ideas, designing and building models, conducting investigations, gathering, analyzing and interpreting information and data, drawing conclusions and reporting out their findings. Every cycle is *situated* and driven by a contextualizing activity. In design sessions, classroom members continuously share their questions and design ideas with their group partners, while in pin-ups they share their solutions with their classmates, helping to generate a sense of belonging to a *community* of designers. In feedback sessions, while sharing and critiquing of each others ideas, the students are encouraged to engage in disciplinary *discourse*, not unlike what would be found existing among a community of professional designers.

**SITE:**

This study refers to the enactment of the Safer Cell Phones curriculum in the 1999-2000 academic year in a high school located in the Midwest. The school was a small public charter school situated within a museum dedicated to the role of innovative American technologies and the stories of the people responsible for these inventions. Students participate in a traditional curriculum consisting of mathematics, science, English, civics, art, and physical education. The Safer Cell Phone curriculum was a nine or five week unit in an 18-week

science "elective" course and all students in the 9th grade were assigned to take the course. This "elective" course was taught during both the first and second semesters.

**POPULATION:**

75 students participated in the study with approximately 55% African American, 37% white, not of Hispanic origin, and the remaining students being Asian, Hispanic, Arab and multiracial.

Two teachers participated in the study. One was an experienced math instructor who held a master's degree in education, the other was a first year teacher who had a Bachelor's degree in Science and had obtained his certification after his bachelor's degree. Both teachers' team enacted the curriculum in its first version; the less experienced teacher enacted the second and third version. Both teachers were part of an informal professional development program that addressed understanding Design Based Science, and both teachers were part of the curriculum development team and participated in the process of modifying and refining the curriculum.

**METHODOLOGY:**

Quantitative methods consisted of science content knowledge pre and post-tests, and pre and post attitude questionnaires. Qualitative methods included observations of the classroom, video documentation of specific lessons, and interviews with target students. The quantitative data was collected for each of the three versions of the curriculum. The qualitative data was collected for the first and third iterations of the curriculum, but are not reported in this paper.

The attitude questionnaire was made up of two parts. The first was a semantic differential questionnaire that consisted of 15 semantic differential scales. It was construct validated by using a factor-analytic investigation (varimax rotated). Three factors were retained, covering 62% of the total variance. These three factors addressed affective, cognitive, and applicability attitudes. These items are reported in Appendix 2. Each item is a member of a subgroup for a difference construct, these constructs are reported in Appendix 3. The second part consisted of a questionnaire containing 47 items aimed at probing students' attitudes towards science and science learning. The items were adapted from a work done by Tal and her colleagues (Tal et. al., 2000) based on the work of Midgley and her colleagues (Midgley et. al., 1998). The scale measuring students' attitudes was a Likert type, 1-5 scale inventory (in which 1=not at all true while 5=very true). Example items are reported in Appendix 4. Each item is a member of a subgroup for a different motivation and attitude construct and these are reported in Appendix 5.

The content knowledge test consisted of 15 multiple-choice questions and 5 open-ended questions. The test probed for different levels of comprehension using low, medium, and high cognitive demand items that focused on the specific science content and the design process that was addressed in the curriculum (Krajcik, et al. 2000). The multiple-choice questions were in the low and medium cognitive demand category; the open-ended questions were in the medium and

high cognitive demand category. This test was administered by the teachers as both a pre and post-test in order to describe the knowledge that the students in the study held and gained. Example items are reported in Appendix 6.

## METHODOLOGY ISSUES

We have two concerns with our methodology. These issues are being reported because we believe that these issues impact the results of the data analysis and the interpretation of these results.

### Population Differences

Version one of the curriculum was enacted during semester one of the 1999-2000 school year. The 50 students participating in the enactment of version one were entering 9$^{th}$ graders who were new to high school and to each other. In addition, these 50 students were grouped together based on their scores on a mathematics achievement test taken before school started. Many of these students scored below the 9$^{th}$ grade level, and were placed together to receive some math content remediation in a mathematics elective course.

Version three was enacted in the latter part of the second semester of the 1999-2000 school year. These students had already taken the required ninth grade mathematics and science course during the first semester of the school year. In addition, the instructor that taught the safer cell phone unit was the ninth grade science instructor. The concepts of electricity, circuits, and battery chemistry were covered by this instructor in the 9$^{th}$ grade science course, including some of the same laboratory activities. These students were grouped together because many of them scored at or above grade level on the mathematics achievement test taken before entering 9$^{th}$ grade.

### Science Content Test Differences

Due to the changes to the curriculum, several items on the science content test needed to be modified or replaced. These questions either dealt with topics that were not addressed in the new version of the curriculum, or they were worded or structured poorly. Since the teachers used the post-tests as their unit exams, in order to assist the teacher in giving a course grade, a decision was made to revise the post-test of the third revision, thereby making the test a better measure of student learning. This meant that comparisons could not be made between one multiple-choice item and all of the open-ended questions for version 1 and version 3 of the curriculum.

## DATA ANALYSIS METHODS

Paired t tests (one tailed, alpha = .025) were run for the total pre and post test mean scores of the content tests and on the means scores for each item of the pre and post content tests. Effect size was calculated for the total mean pre and post-test differences. For the attitude questionnaires, means were calculated for each sub grouping of questions, and paired t tests were run for these means. When comparisons were made between version one and version three pretests, post-tests, or attitude subgroup means, unpaired t tests were performed.

***FINDINGS FOR THE VERISON 1 CURRICULUM ENACTMENT (Semester 1)***

***Attitude Surveys:***

For Part One of the attitude questionnaires, the semantic differential items, significant differences were only seen on the cognitive grouping of items ($p < .05$), with no differences on the affective and applicability of science groupings. For Part Two, the Likert scale questionnaire, there were significant improvements on three subgroups; Personal Mastery Goal Orientation towards learning in science ($p<.01$), reliance on Extrinsic goals in science and Science Attitudes ($p<.05$). There were no differences between the pre and post questionnaires on the other nine subgroups. The implications are that this group of students ended the unit with higher self-ratings for science being "easy, simple, and clear." These students end the unit rating themselves higher on their personal interest towards learning science and their self-directed learning while in science class. Interestingly, they also rated themselves higher on their interest in getting good grades and pleasing the teacher. Their positive attitudes towards science increased from the start to the end of the unit.

***Science Content Tests:***

For the science tests the total mean scores were calculated and a comparison of means was made after removing the unmatched data (n=47). The results identified a significant difference ($p<.001$) between the pre and post-tests total mean scores. The Semester 1 pre-test mean was a 4.10 with a standard deviation of 1.83 and the post-test mean was 6.70 with a standard deviation of 2.06. The calculated effect size for this difference was 1.44 SDs.

***FINDINGS FOR THE VERISON 3 CURRICULUM ENACTMENT (Semester 2)***

***Attitude Surveys:***

Students ended this unit with no significant differences on any of the groupings of the semantic differential, and on any of the 12 subgroups for the Likert scale questionnaire. While there were no significant improvements, there are also no significant decreases, indicating that the changes in the amount of science content included in the curriculum did not affect student attitudes toward their interest in and learning about science.

***Science Content Tests:***

For the science content tests, the total mean scores were calculated and unmatched data was removed (n=23). However, this time the total scores were calculated using 14 of the 15 items because one item was modified between the administration of the pre and post-test. In the second semester, the pretest mean score was 7.70 with a standard deviation of 2.87. The post-test scores mean was 9.57 with a standard deviation of 1.73. The paired samples t test yielded a significance between pre test and post test means scores ($p = .001$). The calculated effect size for the semester 2 results was .651 SDs.

Analyzing the pre and post score mean difference by item revealed some results that may help explain the lower effect size. Significant differences ($p<.001$) were seen on five items. These items addressed the concepts of describing electron flow, identifying examples of electromagnetic waves, explaining the potential difference in a battery, identifying a correctly built circuit (a TIMMS item) and a process question identifying the different stages in the design process. Five items yielded no statistically significant difference; three items had a high pre-test score and two items had no difference between pre and post-test scores. The high pretest scores dealt with defining what a cellular phone is, defining the type of energy change in a battery, identifying what form of electromagnetic radiation causes sunburn, and describing how the radiation in a cellular phone is different from that of a microwave. Three items showed a decrease between the pre and posttest score; one item was on the testing of designed objects, and two items addressed how the model of the atom is used to explain electrical flow in a wet cell. The design question addressed a design topic that had been removed from version three of the curriculum and perhaps the content of this question was confusing to students at the end of the unit. The reasons for decreases on the two items addressing electrical flow in a wet well will be addressed in the teacher capabilities of the results and discussion section of this paper.

## RESULTS AND DISCUSSION

The third version of the Safer Cell Phone curriculum was redesigned in order to provide more depth and detail to the science content while spending less time on the content associated with the discipline of design. The process elements of design that remained in the curriculum included the design goal, the cycles of revision and reflection, and the pin-ups and critiques. These design studio process elements were not taught as separate lessons, but integrated into the daily classroom activities of the curriculum. The science content was increased by adding a new battery laboratory, an electromagnetic wave laboratory, readings on both of these topics, questions about the readings, and short answer questions and quantitative problem sets concerning the science principles associated with the concepts of battery chemistry, and electromagnetic waves and energy.

The results we obtained support our desired goal; we were able to increase the science content in the curriculum without decreasing student interest in science or the interest in the units. In addition, significant content score gains were achieved on the science content tests for both versions of the curriculum. However, we are left with an issue to address.

- Why did we not see a larger increase in learning on the post-test scores that reflects our increase in the depth of the science content added to the curriculum?

In the following discussion, we will explore these issues by examining three key differences between the curricular enactment's; Student prior knowledge

differences between groups, differences in student motivation when engaging in project-based work and differences in teacher capabilities, and differences in school policies and management.

**Differences due to prior knowledge**

Students were not randomly assigned to the different versions of the curriculum. The school administration decided to sort students into the first and second semester elective course based on the scores that students received on a math achievement test taken prior to entering the 9th grade. Many of the students who participated in the enactment of the 3rd version of the curriculum scored at or above their grade level on this test. We might then infer that these same students would also be high achievers if they were to have taken a science achievement test. While we cannot support this math and science achievement correlation empirically, we can examine and compare the science content pretest scores between groups.

Pre-test score comparisons indicate entering knowledge differences between the version groups. Version 1 had a pre-test mean of 4.10, SD = 1.8 and the version 3 students had a pre-test mean of 7.70, SD = 2.87. It is possible that we did not see larger gains for these students because their starting scores did not provide much room for gain on our science content test. Larger gains on the version 3 post test may have required a larger cost in terms of student instructional effort, teacher capabilities regarding the science content, and the time provided for the instructional tasks. The degree that these issues may have impacted the potential for post-test gains will be discussed in the next sections.

**Differences due to student motivation**

Many of the components of the DBS curriculum are similar to the components of project based science curricula. Students have design goals similar to driving questions, students investigate real world phenomena, students create artifacts, students collaborate, and students utilize technology (Krajcik et al., 1998). Blumenfeld, Soloway, Marx, Krajcik, Guzdial, and Palinscar (1991) make this comment about student motivation in project-based science;

> "It is insufficient to provide opportunities designed to promote knowledge that is integrative, dynamic, and generative if students will not invest the effort necessary to acquire information..."
> (Blumenfeld et. al. 2000, pg 375)

The novel and varied activities found in the innovative DBS instructional materials may also provide opportunities to motivate student learning. However, exposure to interesting content and laboratory activities alone does not determine that measured learning will take place. The students need to find the tasks worthwhile and they need to put in the effort to learn the science content to see any changes between pre and post test scores.

Due to the nature of the semester class schedule at the research school, students in version three of the DBS curriculum entered the elective course after having spent a semester in the 9th grade science course. Several of the content

topics that were added to version 3 of the DBS curriculum were content topics that these students had previously covered in the first semester science course. In addition, the 9th grade science teacher was also the elective teacher, and he choose to add several of the DBS laboratory activities to the 9th grade science course. Unfortunately, this meant that the version 3 students repeated many of the laboratory activities and much of the science content for batteries. These students did not experience novel and varied activities in their elective course.

In examining the student scores on the attitude questionnaire, we find that these students in version 3 of the curriculum scored significantly ($p<.001$) lower on the post question scores of classroom enjoyment subgroup than did the semester 1 students. The attitude mean of the version 3 students was 2.65 while the attitude means of the version one students was 3.88. These classroom enjoyment differences provide support for why the post-test scores on version 3 of the DBS curriculum may not have increased as much as we expected. Students were not investing the necessary effort to address the demands of learning the added science content. Students may have seen the repeating of similar topics as a sign that the course was too easy and they did not engage in learning because they felt they had already learned the science material in their first semester science class. The learning that did take place may have been by the students who did not learn the content the first time around. Version 3 may have only succeeded in raising the scores for a subset of the students participating in the curricula enactment.

**Differences due to teacher capabilities**

The Design Based Science curriculum materials embodied many ideas associated with science education reform. Because of this, implementing the curriculum in the school requires more than just delivering the curriculum materials to the teachers.

> "All innovations present requirements that need to be addressed to achieve success...the materials require considerable teacher ability in terms of knowledge and pedagogy" (Blumenfeld et. al. 2000, pg 155.)

While the DBS curriculum enactments included in room teacher support and professional development for the processes of DBS, it did not have a professional development component that addressed the increase in depth of the science content. Students in the version 3 group showed significant gains on the post-test questions related to the process of DBS. However, when the in-classroom support was removed, and the teacher enacted the activities related to battery electrochemistry on his own, the researchers witnessed expressed misunderstandings of the concepts on the part of the teacher. These same content misunderstandings are seen in the errors that students made on the version 3 post-test items that correspond to battery electrochemistry. Clearly, teacher professional development must include both process and content support.

**Differences due to school policies and management**

The policies in place in the school and how these policies are managed can affect the success of an instructional innovation in a school (Blumenfeld, et al. 2000). The DBS curriculum was first enacted in the fall of 1999, the first fall the school was operating under its new block schedule with the new elective courses in place. By the second semester of that year, the principle had made several changes to the classes to accommodate the demands of this new block schedule. As a consequence of these schedule changes the elective course that the DBS curriculum was enacted in went from having nine weeks available to enact the curriculum to only having five weeks available for enactment.

In addition, the elective course was team-taught the first semester. By the end of the first semester the more experienced teacher in the team was pulled out to work in a math remediation course and the inexperienced teacher was left to work on his own. This meant that the increase in depth to the science content was accompanied by a decrease in the time that was available to address this content in class. Both the teacher and the students had less time to work with more science material.

**CONCLUSIONS AND IMPLCATIONS**

Successful gains in knowledge were accompanied with no changes in student attitudes when changes were made to the DBS curriculum. Differences in the outcomes of the posts tests for the two versions of the curriculum may be due to four key reasons: differences in student prior knowledge, differences in student motivation, differences related to teacher capabilities, and the school scheduling policies. These issues may have influenced how the third version of the DBS curriculum was enacted contributing to the lower gains in the post-test scores.

These comparisons of the different enactments of the DBS curriculum suggest some implications for both student needs and reform practice when implementing new DBS instructional innovations. First, student and teacher content needs must be addressed. This can be done through a clear articulation of the content that will be addressed to prevent an overlap between the content addressed in the DBS curriculum and what is taught in the other science courses. Second, teacher professional development must address both DBS process and DBS content needs of the participating teachers. Changes to the content in any curriculum revision must be accompanied by changes to how the content capabilities of the teachers are supported. The innovation that is presented by DBS requires support to be successfully implemented and sustained.

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Appendix 1: Chart summarizing Cell phone curriculum revisions

| | Learning About Design | Learning About Science | DBS Cycle |
|---|---|---|---|
| 1st | Design goals, target market, business vision, case study | Define concepts, Build a battery, battery and sound reading | Partial: Design goal, Research & Pinups |
| 2nd | Design goals, target market, business vision, case study | Define, build battery & speaker, sound, battery, EM reading, | Partial: Design goal, Research & Pinups |
| 3rd | Design goals, target market | Define concepts, 2 battery labs & readings, 1 EM radiation lab, readings, and problems. | Full cycle |

## Appendix 2: Attitude Questionnaire Semantic Differential Scales:

**Directions:**

In this exercise you will rate which word best describes how you think about an idea.

**Example;**

Please circle the number that is nearest to the word that best describes your view of rap music.

**If you think rap music is important, you would circle 1 for the example below:**

Example: Rap Music is:

*Important* (1) 2 3 4 5 *Unimportant*

**If you don't care about rap music, you would circle 3 for the example below:**

Example: Rap Music is:

*Important* 1 2 (3) 4 5 *Unimportant*

**And if you don't like rap music, but you think it is okay, you might circle 4 for the example below:**

*Example: Rap Music is:*

*Important* 1 2 3 (4) 5 *Unimportant*

Please circle the number that is nearest to the word that best describes your view of **science**.

### Science is:

| | | | | | | |
|---|---|---|---|---|---|---|
| Important | 1 | 2 | 3 | 4 | 5 | Unimportant |
| Beautiful | 1 | 2 | 3 | 4 | 5 | Ugly |
| Vague | 1 | 2 | 3 | 4 | 5 | Clear |
| Precise | 1 | 2 | 3 | 4 | 5 | Not precise |
| Frightening | 1 | 2 | 3 | 4 | 5 | Encouraging |
| Simple | 1 | 2 | 3 | 4 | 5 | Complicated |
| Helpful | 1 | 2 | 3 | 4 | 5 | Not Helpful |
| Exhausting | 1 | 2 | 3 | 4 | 5 | Enthusiastic |
| Easy | 1 | 2 | 3 | 4 | 5 | Difficult |
| Useless | 1 | 2 | 3 | 4 | 5 | Essential |
| Interesting | 1 | 2 | 3 | 4 | 5 | Boring |
| Attractive | 1 | 2 | 3 | 4 | 5 | Unattractive |
| Confusing | 1 | 2 | 3 | 4 | 5 | Ordered |
| Necessary | 1 | 2 | 3 | 4 | 5 | Not Necessary |
| Difficult to understand | 1 | 2 | 3 | 4 | 5 | Easy to Understand |

**Appendix 3: Attitude Questionnaire Semantic Differential Sub-groupings:**

| Subgroup Construct | Item Number |
|---|---|
| Affective | 2,5,8,11,13 |
| Cognitive | 3,4,6,9,14,15 |
| Applicability | 1,7,10,12 |

**Appendix 4: Example Attitude Questionnaire Likert Scale questions:**

**Directions:** Please answer the following questions about your experience in science class this year. Indicate your answer by circling a number 1 (not true at all) through 5 (very true). You can use any number on the scale.

1. An important reason why I do my work in science is because I like to learn new things.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not true at all | | somewhat true | | very true |

2. When I show I can answer questions in science, the teacher gives me harder questions to think about.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not true at all | | somewhat true | | very true |

3. When doing my work in science, I stop once in a while and go over what I have done.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not true at all | | somewhat true | | very true |

4. An important reason I do my science work is because I know I will get graded on it.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not true at all | | somewhat true | | very true |

7. I think learning about science is useful.

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not true at all | | somewhat true | | very true |

**Appendix 5: Subgroups for different motivation and attitude constructs used on Attitude Questionnaire part 2.**

| Construct | Item Number |
|---|---|
| Personal Mastery Goal Orientation | 1,14,18,29,46 |
| Extrinsic Goals | 4,15,23,33,45 |
| Science Attitudes | 7,12, 34, 44 |
| Technology Attitudes | 5, 25,31,40 |
| Thoughtfulness | 3, 6,9,17, 30, 46, |
| Thoughtfulness in Inquiry | 13,19,32,36,37 |
| Classroom Enjoyment | 10,22,42,47 |
| Science Beliefs | 28,38 |
| Perception of Classroom - Investigation | 8,24 |
| Perception of Classroom - Cooperation | 16,20 |
| Perception of Classroom - Involvement | 11,21 |
| Press for Understanding | 2,9,26,27,35, 41 |

**Appendix 6: Example Science Content Test items.**

Low cognitive Demand Science Content:

4. Which of the following is different?

   A. microwaves
   B. visible Light
   C. Sound waves
   D. X-rays

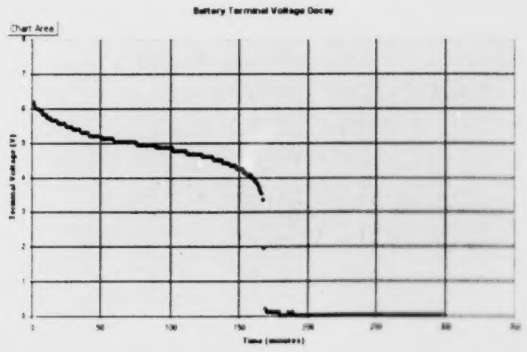
Medium Cognitive Demand Science Content

6. Which of the following EM wavelengths has the highest frequency?

   A. .01 meter
   B. 1.0 meter
   C. 10 meters
   D. 100 meters

High Cognitive Demand Science Content

16. The following shows a discharge curve of a battery.




17. Explain the relation between voltage and time._____

18. Explain the change of the slope of the curves. ._____

19. Assuming that a personal computer needs at least 5.3V to operate, would you choose this battery for operating your personal computer?

Yes ____ No ____

Why:

_____

Low Cognitive Demand Design Process

14. The first stage in a design project is

A. building a prototype.

B. locating a market need.

C. creating a computerized model.

D. reviewing existing technology and scientific knowledge.